Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 61 (2014) 2141 – 2144

Energy Procedia

The 6th International Conference on Applied Energy – ICAE2014

Investigation of a heat pipe heat exchanger integrated with a water spray for the heat recovery from boil exhaust gas

Ye Yuan[a], Yiji Lu[a], Huashan Bao[a], Yaodong Wang[a], Wen Wang[b], Anthony Paul Roskilly[a]

[a] *Sir Joseph Swan Centre for Energy Research, Newcastle University, Newcastle NE1 7RU, UK;*
b Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University, Shanghai, 200240, China;

Abstract

This paper presents a thermodynamic analysis and a numerical simulation of a heat pipe heat exchanger which recovers both sensible and latent heat from the exhaust gases of boiler with a temperature range from 450K to 600K. Compared with the conventional methods of preventing corrosion by avoiding acid dew point or using the anticorrosive material, a water spray is proposed in this work as an innovation to integrate with the heat pipe heat exchanger, which absorbs the corrosive gas such as SO_2, SO_3 and NO_x from the outlet of boiler. The comprehensive theoretical study has shown the convective heat transfer coefficient under wet condition is 1.5-3 times higher than that of dry condition and the optimal location of the water spray in the system has been identified. Meanwhile a the heat and mass transfer in a thirty-row heat pipe heat exchanger with different locations of a water spray has been established by the FLUENT to analyze the flow field and temperature gradient of the heat pipe heat exchanger. The overall analysis has proven that system efficiency of the boiler and the lifetime of heat exchanger can be effectively enhanced with the application of the water spray.

Peer-review under responsibility of the Organizing Committee of ICAE2014

Key words: heat pipe, water spray, boiler exhaust gas, heat and mass transfer, thermodynamic analysis,numerical simulation

1. Introduction

Heat pipe technology has been widely applied in ventilation heat recovery, computer cooling system, nuclear cooling system and space craft due to its excellent heat transfer capacity and flexible structure. During the application of heat pipe in the ventilation heat recovery system, the heat pipe normally servers as a heat exchanger integrated with adsorption refrigeration system. To approach higher heat recovery efficiency, lower outlet temperature of exhaust gas in heat pipe heat exchanger is preferred. However, once the temperature of exhaust gas drops below the acid dew point, the acid gases such as SO_2, SO_3 and

* Corresponding author. Tel.: +44-77-8411-2323.
E-mail address: y.yuan4@ncl.ac.uk.

Peer-review under responsibility of the Organizing Committee of ICAE2014
doi:10.1016/j.egypro.2014.12.094

NO_x will condense into liquid phase and then corrode the heat exchanger. By avoiding the acid dew point and utilizing anticorrosive/hydrophilic materials can prevent the corrosion problem. However, these conventional anticorrosion methods would reduce the heat recovery efficiency and increase the cost of system.

In this work, a heat pipe heat exchanger integrated with water spray is presented to solve the previous problems. The novel design not only can control the acid condensing location but also makes it easier to replace the simultaneously rows of heat pipes in condensing location without disassembling the whole unit, which means that the life time of the heat exchanger can be extended. Meanwhile, the convective heat transfer coefficient will be improved under the dehumidifying condition, which can increase the overall heat recovery efficiency.

2. Thermodynamic analysis

To simplify the model, only fully dry and fully wet conditions are considered for calculation. The convective heat transfer coefficient is calculated based on correlation of Nusselt number, Renolds number and Prandtl number in fully dry condition.

$$\mathrm{Nu} = 0.137\mathrm{Re}^{0.6338}\mathrm{Pr}^{\frac{1}{3}} \tag{1}$$

Because the exhaust gas can be recognized as saturated steam in fully wet condition, the concept of moisture separation coefficient ξ is brought into the calculation as convective heat transfer coefficient.

$$\xi = \frac{h_{in} - h_{out}}{Cp(t_{in} - t_{out})} \tag{2}$$

h_{in}, h_{out} are inlet and outlet saturated steam enthalpy; C_p is the specific heat capacity of dry exhaust gas; t_{in}, t_{out} are inlet and outlet temperature.
The convective heat transfer coefficient under fully wet condition is determined by

$$h_w = \xi h_d \tag{3}$$

Where h_w is the convective heat transfer coefficient under fully wet condition; h_d is the convective heat transfer coefficient under dry condition.

3. Modelling and simulation

A thirty-row heat pipe heat exchanger model has been established to optimize the location of the water spray. The detailed parameters of the heat exchanger are shown as follows.

Table 1. Parameters of heat pipe heat exchanger

parameter	value	parameter	value
Internal diameter of pipe, d_i (m)	0.027	External diameter of pipe, d_0 (m)	0.032
External diameter of fin, d_f (m)	0.056	Fin height, h (m)	0.012
Fin thickness, t, (m)	0.0004	Fin pitch, p (m)	0.003
Length of evaporating, L_e (m)	2.4	Length of condensing, L_c (m)	1.8
Heat pipe amount for each row, n	18	Amount of rows, m	30
Total amount of heat pipes, N	540	Pipe arrangement	staggered
Crosswise pitch, S_1 (m)	0.066	longitudinal pitch, S_2 (m)	0.057

The smallest repetitious unit, which is shown as the blue area in Fig.1, is picked for calculation. The unit contains thirty rows in Z direction and a fin pitch in Y direction.

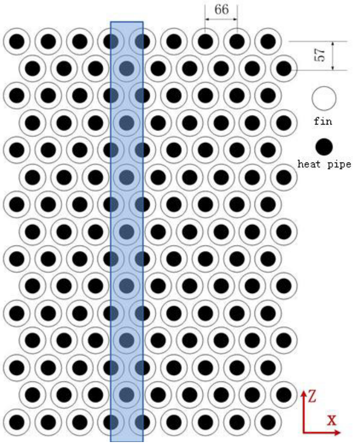

Fig. 1. Partial sketch of the model (X-Z plane)

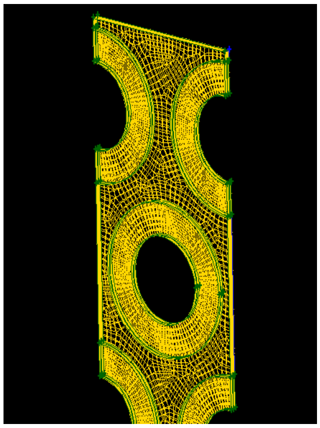
Fig. 2. Mesh of a unit

The assumptions applied in the model are,
1. Condensing phenomenon only exists on the surface of fins and external wall of heat pipe.
2. There is no condensate in the calculation area.
3. Temperature of water-side external wall of heat pipe is considered the same temperature as water.
4. The water spray is an external heat resource and has no influence on humidity of exhaust gas.
5. Initial condensate appears when the temperature of fins and external wall of the heat pipe lower than the dew point of saturated steam.
6. The relative humidity of exhaust gas achieves 100% during condensing process.
According to the assumptions, governing equations are chosen as continuity equation, momentum equation and energy equation with energy source item of condensing. The energy source item of condensing equation is as follow.

$$S_T = \rho D_i \frac{\partial Y_i}{\partial \vec{n}}\bigg|_w \frac{\Delta A}{\Delta V} h_l \qquad (4)$$

D_i is diffusion coefficient; Y_i is mass fraction of vapour in saturated steam; A is projected area; h_l is latent heat of water.
The initial conditions of the temperature of exhaust gas and cooling water are set at 453K and 303K, respectively. 15500kg/h is the mass flow rate of exhaust gas and 2500kg/h is that of cooling water.

4. Result and discussion

For heat pipe heat exchanger without water spray, the condensing location is 9th row; outlet temperature of water is 339K; outlet temperature of exhaust gas is 370K and moisture content of exhaust gas is 14.7g/kg. Subsequently heat pipe heat exchanger integrated with water spray (303K) in different locations is analysed, and the result is shown in Fig.3. As shown in Fig.3, the outlet temperature of water increased from 1st row to 8th row and decreased from 8th row. The condensing location has been moved forward by the application of water spray, which absorbs the heat from exhaust gas. The highest outlet temperature of water is achieved at 345.5K, when the water spry locates at 8th row. The calculation results proved that the optimal position for the water spray is at 8th row of the heat pipe.

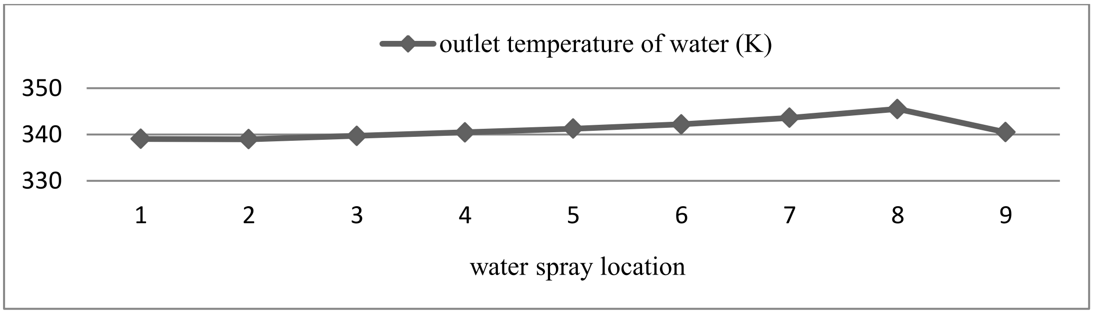

Fig. 3. Outlet temperature of water with different water spray location

A CFD model has been established to find out the condensing process, the results are shown in Fig.4-6. Vortex appears in the leeward side of heat pipe and the temperature at vortex area is lower than surroundings, which is shown in Fig. 5. The temperature distribution of fin is shown in Fig. 6. According to the results, the condensing will starts from leeward side.

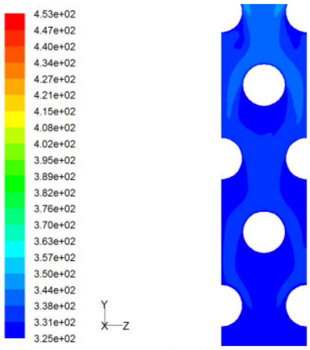

Fig. 4. Temperature distribution

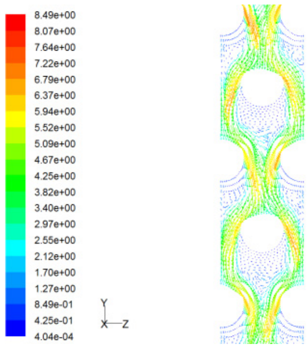

Fig. 5. Velocity vector

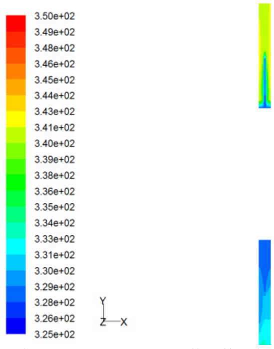

Fig. 6. Temperature distribution of fin

5. Conclusion

In this paper, the potentials of optimizing heat pipe heat exchanger by using water spray have been proved. With the application of water spray, the condensing point inside the heat exchanger has been brought forward by one row, which will effectively increase the overall heat recovery efficiency. Moreover, the water spray serves as a wet scrubber, which can wash out and absorb the acid gases to prevent the corrosion problem. In conclusion, by using the water spray not only can benefit the efficiency but also extend the life time of the heat exchanger.

Acknowledgement

This research outcome is from the EPSRC funded projects (LH Cogen - EP/I027904/1 and GLOBAL - Sustainable Energy through China-UK Research Engagement (SECURE) - EP/K004689/1).

References

[1]Qun Chen , Karen Finney, Hanning Li, Xiaohui Zhang, JueZhou, Vida Sharifi, Jim Swithenbank, Condensing boiler applications in the process industry
, *Applied Energy*, 2012, **89**:30–36

[2]F. Haase, H. Koehne, Design of scrubbers for condensing boilers, *Progress in Energy and Combustion Science*, 1999, **25**:305–337